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MARCO AURÉLIO DE CARVALHO

"THE EFFECT OF PLATFORM CONNECTION AND ABUTMENT MATERIAL ON STRESS DISTRIBUTION IN SINGLE ANTERIOR IMPLANT-SUPPORTED RESTORATION: A 3D FINITE ELEMENT ANALYSIS"

"A INFLUÊNCIA DO MATERIAL E CONEXÃO DE PILARES NA DISTRIBUIÇÃO DE TENSÕES EM COROAS ANTERIORES SOBRE IMPLANTES: UM ESTUDO PELO MÉTODO DOS ELEMENTOS FINITOS."

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UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

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Orientador: Prof. Dr. Guilherme Elias Pessanha Henriques

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Dissertação apresentada à Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, para obtenção do título de Mestre em Clínica Odontológica na área de Prótese Dental.

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Este exemplar corresponde à versão final da dissertação defendida pelo aluno Marco Aurélio de Carvalho e orientado pelo Prof. Dr. Guilherme Elias Pessanha Henriques.

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“No meio da dificuldade
encontra-se a oportunidade.”

Albert Einstein

RESUMO

A reabilitação de elementos unitários com implantes osseointegrados na região anterior da maxila é um cenário desafiador diante dos requisitos estéticos e funcionais. Nesse contexto, diferentes tipos de conexões pilar/implante e materiais constituintes do pilar surgiram no intuito de suprir as exigências estético-funcionais atuais. A distribuição de tensão no sistema de restaurações cimentadas a pilares cerâmicos parafusados a implantes é um fator importante na elucidação do processo de falha e também na previsibilidade de sucesso do tratamento. O objetivo do trabalho foi avaliar o efeito de diferentes conexões e materiais de pilar na distribuição de tensões em restaurações sobre-implante unitárias anteriores através do método dos elementos finitos. Foram obtidos 9 grupos experimentais a partir da combinação de três conexões protéticas (hexagonal externa-HE, hexagonal interna-HI e cone morse-CM) e três tipos de material constituinte do pilar (titânio-Ti, zircônia-Zr e híbrido-H): HETi, HEZr, HEH, HITi, HIZr, HIH, CMTi, CMZr, CMH. Com o auxilio do *software* de modelagem 3D (SolidWorks 2012 Corp., Concord, MA, EUA), foram obtidos os modelos geométricos que se constituíam de: segmento anterior de maxila; implantes HE, HI e CM construídos a partir do implante Titamax Ex 4x13mm (Neodent, Curitiba, Brasil); pilar do tipo Munhão Anatômico CM (Neodent, Curitiba, Brasil) em titânio, zircônia e híbrido (corpo em zircônia e base em titânio) para implantes HE, HI e CM; coroa do elemento 21 em dissilicato de lítio cimentada com cimento resinoso. Foi aplicada uma carga, de 49N em 45 graus em relação ao longo eixo do dente, de forma contínua em 6 etapas desde a região de cíngulo à borda incisal, no intuito de simular o movimento de excursão da guia incisal. O critério de Tensão Equivalente de von Mises (σ_{vM}) foi utilizado para a avaliação quantitativa e qualitativa dos implantes e pilares entre os nove grupos. As tensões máxima (σ_{max}) e mínima (σ_{min}) principais foram utilizadas para a avaliação quantitativa entre os pilares de zircônia e corpo de zircônia de pilares híbridos. Os maiores valores de σ_{vM} (MPa) para o pilar foram encontrados nos grupos CMZr, CMH e CMTi (315,61;

293,61; 289,36 respectivamente), e os menores nos grupos HEH, HITi e HIH (91,70; 97,58; 100,65, respectivamente). Os valores σ_{max} e σ_{min} foram menores nos grupos H que nos Zr. Qualitativamente, a concentração de tensão se deu na interface pilar/implante em todos os grupos, independente da conexão ou material do pilar. Concluiu-se que o tipo de conexão teve maior influência que o material constituinte nas tensões acumuladas nos pilares, sendo que os pilares híbridos tiveram comportamento mecânico semelhante aos de titânio, que por sua vez foi melhor que os pilares em zircônia.

Palavras-chave: pilar, zircônia, conexão protética, método dos elementos finitos.

ABSTRACT

The anterior single crown reconstruction is still a challenging scenario in implant dentistry. Within the esthetic and functional demand, different platform connections and abutment material emerged for better outcomes. The stress distribution through the structure is an important factor to be elucidated for better fail process understanding and also to the treatment success predictability. Therefore, the aim of this study was to evaluate the effect of different abutment material and platform connection on stress distribution in single anterior implant-supported restorations, through the finite element method. Nine experimental groups were design from the combination of three platform connection (external hexagon-EH, internal hexagon-IH and morse tapered-MT) and three abutment material (titanium-Ti, zirconia-Zr and hybrid-H): EHTi, EHZr, EHH, IHTi. IHZr, IHH, MTTi, MTZr, MTH. Finite element models were obtained with the aid of a modeling software (SolidWorks 2012 Corp., Concord, MA, USA), and consisted of: EH, IH and MT implants modeled from Titamax Ex 4x13mm (Neodent, Curitiba, Brazil); abutment modeled from Anatomic Abutment CM (Neodent, Curitiba, Brazil) in titanium, zirconia and hybrid (two-piece abutment); lithium disilicate central incisor crown cemented over the abutment. The occlusal loading, consisted of a magnitude of 49N in 45 degrees to the implant long axis, was applied in six steps in order to simulate the incisal guidance. The equivalent von Mises criterion (σ_{vM}) was used for both qualitative and quantitative evaluation of implant and abutment among all groups. The maximum (σ_{max}) and (σ_{min}) minimum principal stresses were obtained for numerical comparison of zirconia abutment and zirconia abutment body. The highest abutment σ_{vM} (MPa) occurred in MTZr, MTH and MTTi (315.61; 293.61; 289.36 respectively); and the lowest in EHH, IHTi and IHH (91.70; 97.58; 100.65, respectively). The σ_{max} and σ_{min} values were lower in H groups than Zr groups. The stress distribution concentrated in the abutment/implant interface in all groups, regardless the platform connection or abutment material. It was concluded that the platform connection had more influence than abutment material on stress values and distribution on abutments, and the stress values for implants were similar among different platform connections, but greater stress concentrations were observed in internal connections.

Key words: abutment, zirconia, platform connection, finite element analysis

SUMÁRIO

INTRODUÇÃO

Implantes dentários são comumente usados para reabilitação de perdas dentárias desde totais a unitárias (Papaspyridakos et al., 2013; Lambert et al., 2009; Barias et al., 2013). Na região anterior, o tratamento unitário com coroa implantossuportada representa um dos maiores desafios da odontologia estética atual (Délben et al., 2012; Freitas Júnior et al., 2010). Tanto os implantes quanto os pilares são comumente fabricados em ligas de titânio devido à sua biocompatibilidade e propriedades mecânicas bem documentadas (Linkevicius & Apse, 2008). Entretanto, o resultado estético se tornou critério adicional ao se avaliar o sucesso de uma reabilitação, e apesar da muitas modificações no desenho e fabricação de pilares metálicos, o uso desses não atende à esse requisito em algumas situações (Nakamura et al., 2010). Em caso de recessão gengival, a exposição do pilar acinzentado leva ao fracasso da restauração em regiões anteriores. Além dessa condição, quando do uso de pilar metálico em pacientes com biotipo gengival fino, um aspecto acinzentado pode ser observado por transparência (Ronald & Jung et al., 2007; Park et al., 2007). Uma melhora substancial dessa condição pode ser alcançada com o uso dos recentes pilares cerâmicos disponíveis.

Os primeiros pilares cerâmicos foram introduzidos no mercado em 1993 (CerAdaptTM, Nobel Biocare, Gotemburgo, Suécia), confeccionados em alumina, uma cerâmica de alta resistência sendo indicados exclusivamente para o uso em implantes com conexão hexagonal externa (Andersson et al., 2001). Os pilares CerAdaptTM eram customizados através do desgaste manual para se chegar às proporções anatômicas desejadas em cada caso. Apesar do benefício estético, em estudos clínicos, a fratura desses pilares chegou à 7% dos casos após um ano (Andersson et al., 2001). Tendo em vista a baixa performance mecânica comparada ao titânio e os relatos clínicos de fratura, buscou-se um material cerâmico com melhores propriedades mecânicas que culminou, nos primeiros anos da década de 1990, na introdução da zircônia estabilizada por ítrio (Conrad et al., 2007). Com valores de resistência flexural de 900 à 1400 MPa, dureza Vickers de 1200 e tenacidade à fratura de 10 a 12 MPa m0,5 (quase duas vezes superiores à alumina), a zircônia se mostrou um material restaurador promissor (Blatz et al., 2009; Çaglar et al., 2011; Yildirim et al., 2003).

Os pilares em zircônia oferecem vários benefícios em relação aos tradicionais metálicos. Primeiramente, quando se envolve região estética, sua superioridade já é bem documentada devido às suas propriedades ópticas (Ronald & Jung et al., 2007; Bressan et al., 2011). Um segundo benefício está relacionado à biocompatibilidade, em que já se observou uma menor adesão bacteriana na zircônia quando comparada ao titânio (Scarano et al., 2004) e uma barreira mucosa favorável na região perimplantar, devido à melhor inserção de fibras propiciada pela zircônia (Welander et al., 2008). Os resultados apresentados em estudos clínicos com pilares cerâmicos têm sido promissores, sendo que a resistência mecânica dos pilares cerâmicos parece ser adequada para o uso clínico como alternativa ao tradicional pilar metálico (Nakamura et al., 2010; I Sailer, Philipp, et al., 2009). No entanto, alguns estudos laboratoriais demonstram maior fragilidade dos pilares cerâmicos, relatando fratura dos mesmos (Henriksson & Jemt, 2003; Aboushelib & Salameh, 2009).

Umas das deficiências das cerâmicas é seu comportamento mecânico, que apesar dos avanços tecnológicos em aumento da resistência intrínseca, continuam sendo frágeis (alta dureza e pouca deformação plástica) e, portanto, menos resistentes às forças de tração e cisalhamento. Defeitos microestruturais internos ao material, combinados às tensões podem gerar trincas e falhas (Belser et al., 2004), que estão mais propensas a acontecer frente à interface do pilar com o parafuso de fixação e com a plataforma do implante, devido à diferenças do módulo de elasticidade, dentre outras propriedades do material (Nguyen et al., 2009; Cho et al., 2002).

Outro parâmetro a se considerar ao avaliar o comportamento biomecânico de um pilar é o tipo de conexão com o implante (Schmitt et al., 2013; Cumbo et al., 2013; Gracis et al., 2012). Conexões externas são amplamente utilizadas na implantodontia, mas com o surgimento das conexões internas, algumas condições mecânicas, biológicas e estéticas foram melhoradas: dissipação das tensões perimplantares (Schmitt et al., 2013; Cumbo et al., 2013; Lewis & Klineberg, 2011), selamento bacteriano na interface implante/pilar (Schmitt et al., 2013; Assenza et al., 2012) e maiores volumes de tecido perimplantar com o uso do conceito de plataforma estendida (Schmitt et al., 2013; Lewis & Klineberg, 2011).

Atualmente, a maior indicação do uso de conexões internas está na reabilitação de perdas unitárias anteriores (Schmitt et al., 2013; Lewis & Klineberg, 2011). Não é incomum, portanto, o uso de pilares cerâmicos com conexão interna nessas condições, mas pouco se sabe do seu comportamento a longo prazo devido ao limitado número de estudos clínicos (Gomes & Montero, 2011). Parece existir uma correlação entre o valores de cargas de fratura em pilares cerâmicos e tipo de conexão (I Sailer, T Sailer, et al., 2009; Zembic et al., 2009).

Nos pilares de conexão interna, a quantidade de material na extensão de interface com o implante é reduzida, o que implica em paredes mais delgadas e portanto mais susceptíveis à falha (I Sailer, T Sailer, et al., 2009). No caso de material frágil como as cerâmicas, em comparação a um material mais tenaz como uma liga metálica, essa condição é ainda mais acentuada. Apesar da alta resistência à fratura, a zircônia apresenta um alto módulo de elasticidade e pouca tenacidade, o que leva à altas tensões nas áreas de contato com o parafuso de fixação e a plataforma do implante (Aboushelib & Salameh, 2009).

Frente às fraturas em conexões internas, o uso de pilares híbridos tem sido associado a melhores comportamentos mecânicos (I Sailer, T Sailer, et al., 2009). Isso se dá pela associação das melhores propriedades mecânicas na interface parafuso/pilar/implante, que estão presentes no conector de titânio, com as características estéticas presentes no corpo do pilar em cerâmica. O pilar híbrido se constitui de uma base metálica em titânio parafusada no implante e um corpo em zircônia cimentada sobre esta. Essa montagem possibilita: (a) o melhor comportamento mecânico observado no metal que compõe a interface pilar/implante, devido à sua capacidade de deformações elástica e plástica frente à fadiga; (b) melhor biocompatibilidade (Scarano et al., 2004.; Welander et al., 2008) e comportamento óptico (Bressan et al., 2011; Watkin & Kerstein, 2008) da zircônia, que compõe todo o corpo do pilar acima da plataforma do implante. Há poucos estudos laboratoriais que comparam a resistência à fratura entre as diferentes conexões em pilares totalmente cerâmicos e híbridos, e nenhum estudo que avalia a distribuição das tensões no sistema (Lewis & Klineberg, 2011). O uso de análises biomecânicas virtuais, tal como o método dos elementos finitos, tem sido usado para melhor entender o comportamento das tensões nas estruturas, o qual não pode ser obtido em testes mecânicos. (Pesqueira et al., 2012; Assunção et al., 2009).

Pouco se entende do comportamento das tensões envolvidas nas diferentes combinações de material do pilar e tipo de conexão protética. A elucidação da distribuição de tensão nesses sistemas pode nortear o melhor aproveitamento do materiais e desenhos de conexão na busca de assegurar uma melhor performance mecânica dos pilares unitários cerâmicos a longo prazo. Frente ao exposto, este estudo objetiva analisar, através do Método dos Elementos Finitos Tridimensional, o comportamento biomecânico de pilares e implantes de uma prótese implantossuportada de incisivo central superior utilizando pilares em titânio, em zircônia e híbrido sob condição de conexão hexagonal externa, interna e cone-morse.

CAPÍTULO[1]

The effect of platform connection and abutment material on stress distribution in single anterior implant-supported restoration: a non-linear 3D finite element analysis.

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ABSTRACT

Statement of Problem. Although various abutment connections and materials have been recently introduced, insufficient data exist regarding their mechanical performance due to the stress distribution.

Purpose. This study evaluated the effect of different abutment material and platform connection on stress distribution in single anterior implant-supported restorations, through the finite element (FE) method.

Material and Methods. Nine experimental groups were designed from the combination of three platform connection (external hexagon-EH, internal hexagon-IH and morse tapered-MT) and three abutment material (titanium-Ti, zirconia-Zr and hybrid-H): EHTi, EHZr, EHH, IHTi, IHZr, IHH, MTTi, MTZr, MTH. FE models consisted of 4x13 mm implants; anatomic abutments and lithium disilicate central incisor crown cemented over the abutment. The 49 N occlusal loading was applied in six steps in order to simulate the incisal guidance. Equivalent von Mises stress (σ_{vM}) was used for both qualitative and quantitative evaluation of implant and abutment among all groups and the maximum (σ_{max}) and minimum (σ_{min}) principal stresses for numerical comparison of zirconia parts.

Results. The highest abutment σ_{vM} occurred in MT groups; and the lowest in EHH, IHTi and IHH. The σ_{max} and σ_{min} values were lower in H groups than Zr groups. The stress distribution concentrated in the abutment/implant interface in all groups, regardless the platform connection or abutment material.

Conclusions. The platform connection had more influence than abutment material on stress on abutments. The stress values for implants were similar among different platform connections, but greater stress concentrations were observed in internal connections.

Clinical Implications: For anterior implant-supported restoration, regardless the platform connection, either zirconia abutment attached to titanium base or titanium abutment provide better mechanical behavior than pure zirconia abutments.

INTRODUCTION

The maxillary anterior single crown reconstruction is still one of the most challenging scenarios in modern dentistry due to its esthetic and functional requirement. The replacement of missing teeth using dental implants is well documented as a feasible treatment with high success rates (Schropp et al., 2005; Berglundh et al., 2002). Despite that, esthetic enhancements are still on demand, especially in anterior regions in patients with high smile line (Bressan et al., 2011; Vanlioglu et al., 2012).

The predictability of an esthetic implant outcome can be achieved by overcoming the optical problem caused by gray discoloration of the marginal peri-implant mucosa induced by titanium abutments (Prestipino and Ingber, 1993). Therefore, CerAdapt™ (Nobel Biocare, Goteborg, Sweden), first all-ceramic abutment available, emerged as a solution for tissue discoloration in implant dentistry (B Andersson et al., 1999; Bernt Andersson et al., 2001; Yildirim et al., 2000).

Since then, the esthetic benefit of ceramic abutments over metal abutments has been well documented in clinical and *in vitro* studies (Holst et al., 2005; Ronald & Jung et al., 2008; Bressan et al., 2011; I Sailer et al., 2007; Ekfeldt et al., 2011), although, the mechanical performance is still in debate (C-F Wang et al., 2013; Huynh-Ba et al., 2012). Recently, some authors analyzed the mechanical performance of zirconia abutments with external and internal connections, suggesting lower fracture resistance than titanium abutments, especially in internal connections (Stimmelmayr et al., 2013; Leutert et al., 2012; Kim et al., 2013; Nguyen et al., 2009; Att et al., 2006; Firidinoğlu et al., 2012; Foong et al., 2013).

It should be pointed that internal connections provide joint stability and better resistance against rotational and lateral movements (Bernardes et al., 2009; MP Dittmer et al., 2011; S Dittmer et al., 2011; Pjetursson et al., 2007). However, the abutment internal projection through the implant may lead to greater stress concentration due to the thinner abutment and implant walls presented in abutment/implant interface (Aboushelib & Salameh, 2009). Moreover, fractures in all-ceramic internal connection abutment has been both clinically and *in vitro* reported (Aboushelib & Salameh, 2009; Firidinoğlu et al., 2012; Kim et al., 2013; Ekfeldt et al., 2011; Nguyen et al., 2009).

In order to overcome the fragile properties of zirconia in the implant/abutment interface, the two-piece hybrid abutment emerged as a titanium base (Ti base) assembled to a zirconia abutment body (I Sailer, T Sailer, et al., 2009; Kim et al., 2013). In these abutments, zirconia is milled onto the titanium base that is screwed to the implant (Butz et al., 2005). The joint stability is improved by the internal design made of titanium alloy, and the ceramic body over the implant platform grants the esthetic enhancement. In contrast to all-ceramic abutment, the hybrid abutment showed better load fatigue results, suggesting improved mechanical performance (I Sailer, T Sailer, et al., 2009; Kim et al., 2013; Nguyen et al., 2009; Stimmelmayr et al., 2013).

Despite the recent *in vitro* results with hybrid abutments, the biomechanical behavior among these components and the different platform connections interface are still not well explored. In addition, the use of virtual biomechanical analyses such as the finite elements method, have been considered for understanding the behavior of structure stress, which are not obtained in mechanical tests (Pesqueira et al., 2012; Assunção et al., 2009)

Therefore, the aim of this study was to evaluate the effect of different combinations of platform connections and abutment materials on the distribution of stresses in abutment and implants of single implant-supported anterior restorations through the use of the three-dimensional (3D) finite element analysis (FEA). The null hypothesis was that neither the platform connection nor the abutment material influence the stress concentration on abutment or implant.

MATERIAL AND METHODS

Experimental Design

Nine three-tridimensional anterior maxilla models were created based on a cone beam computed tomographic (CBCT) image (i-CAT Cone Beam 3D Dental Imaging System, Imaging Sciences International). Each models were consisted of dental implants developed from the geometry of a 4x13 mm Titamax Ex implant (Neodent, Curitiba, Parana, Brazil) with different platform connections: external and internal hexagon and morse-tapered, with same macrogeometry (EH, IH and MT, respectively); and a central incisor lithium disilicate crowns cemented over titanium (Ti), zirconia (Zr) or hybrid (H) abutments (Table 1). The 9 experimental models were obtained from the combination of platforms connection and abutment material (EHTi, EHZr, EHH, IHTi, IHZr, IHH, MTTi, MTZr, MTH), using a three-dimensional computer-aided design software (SolidWorks 2013 Corp., Concord, MA, USA) (Fig. 1). FEA was used to determine the maximum (tensile) and minimum (compressive) principal stresses values for zirconia and hybrid abutments and the von Mises stress for all abutments and implants.

Numerical Analysis

After geometry acquirement, all models were exported to ANSYS Workbench FEA software (ver. 14.0; Swanson Analysis Inc., Houston, PA, USA) for biomechanical analysis. The crowns, abutments, screws, implants, compact and cancellous bone were considered to be isotropic, homogenous and linearly elastic (Li et al., 2006; Cruz et al., 2009; Coelho et al., 2009; Albakry et al., 2003)(Table 2).

Discrete FE meshes were generated by using 10-node quadratic tetrahedral elements with 3 degrees of freedom per node. As results of convergence analysis (6%) (Lan & Huang, 2009) the value of mesh size was 0.7 mm. The models presented a number of elements ranging from 91.085 to 93.819, and a number of nodes ranging from 159.965 to 164.975. The boundary conditions were defined by fixing the mesial and distal exterior surfaces of the bony segment in all directions. Immediate loading was simulated by using non-linear frictional contacts elements with a friction coefficient (μ) of 0.3 between the bone and implant (Mellal et al., 2004). Occlusal loading was applied to the palatal surface of the lithium disilicate crown at six different aligned contact areas obtained for the purpose of simulating the excursive movement of the incisal guide. The 49 N loading was applied in 45 degrees relative to the implant long axis (Att et al., 2012).

The maximum (σ_{max}) and minimum (σ_{min}) principal stresses values were obtained for abutment comparison among zirconia and hybrid groups. Equivalent von Mises (σ_{vM}) stress criteria for abutment and implant numerical and color-coded comparison were obtained for all models.

RESULTS

The highest σ_{vM} stress values for abutments and implants in all groups are presented in Figure 2. In order to qualitatively compare all groups, the σ_{vM} stress distribution is displayed for abutments in Figure 3 and implant in Figure 4. The highest σ_{max} and σ_{min} for Zr and H abutments are presented in Figure 5.

Stresses Transmitted to Abutments

Considering the equivalent von Mises stress criterion and connection type, the highest values were found in the MT groups (315.61 MPa for the MTZr, followed by a decrease of 7% and 8% for MTH and MTTi, respectively). Those were concentrated on both buccal and lingual implant/abutment interface areas, at platform level (Fig. 3). The lower value (91.7 MPa) was found in the EHH, followed by a rising of 6.4% and 9.7% for IHTi and IHH, respectively. The stress distribution for the EH groups homogeneously concentrated on the cervical area of the abutment, while for the IH groups, it concentrated in the internal hexagon projection and abutment platform rest area (Fig. 3).

Regarding the abutment material, for titanium groups, the highest σ_{vM} occurred on MTTi, followed by EHTi and IHTi. For zirconia groups, the highest σ_{max} and σ_{min} values in MPa were found in MTZr (332.3, - 380.37), followed by EHZr (107.7, -250.7) and IHZr (178.32, -162.27). Among the hybrid groups, considering only the zirconia abutment body, the order was similar: MTH (194.61, -235.84 MPa), followed by EHH (85.23, -87.63 MPa) and IHH (67.31, -69.73 MPa). Considering the Ti base, the MTH displayed the highest σ_{vM} values (293.91 MPa) followed by a reduction of 13.9% in EHH and 65.7% in IHH.

Stresses Transmitted to Implants

Considering the connection type, the stress patterns were almost the same and also uniformly distributed in the implants, concentrating in the palatal and buccal region of the implant neck and decreasing closer to the implant apex, regardless the abutment material (Fig. 4). The mean σ_{vM} values ranged, in MPa, from 204.64 (SD± 12.13) in MT groups to 220.83 (SD± 3.48) and 261.2 (SD± 15.23) in EH and IH groups, respectively.

For the EH groups, the greater σ_{vM} stress concentration was found in the external face of the first thread of the implant, near to the compact and cancellous bone interface, and reached 237.98 MPa in EHH, with a reduction next to 11% for EHTi and also EHZr. For the IH groups, the maximum σ_{vM} stress was concentrated on the thinnest wall area of the implant caused by the abutment internal hexagon projection, and reached 266.11 MPa in IHTi, followed by a reduction of less than 3% for both IHZr and IHH.
In MT groups, the maximum σ_{vM} stress occurred on the internal upper abutment/implant interface, at bone level, reaching 226.08 MPa in MTH, followed by a reduction next to 15% in MTZr and also MTTi. Differences in the stresses distribution in the implants were greater regarding the connection type than abutment material (Fig. 4).

DISCUSSION

Historically, abutments were manufactured in metal. In order to fulfill the esthetic demand of dentists and patients, ceramic abutments were designed. The peri-implant tissue discoloration can result in the sight, by transparency, of the abutment material, causing a greyish gum aspect. This aspect may be due to a thin gingiva, which cannot block the reflected light from the metallic abutment (Yildirim et al., 2000). The selection of a proper prosthetic solution represents one of the first steps for the achievement of an adequate esthetic result, since it significantly induces the shade and shape behavior of the gingival tissue (DP Tarnow & Eskow, 1996). For the enhancement of the esthetic results, all-ceramic abutments emerged as a promising option (Bernt Andersson et al., 2001).

In addition to esthetic factors, stress concentrations play another important role in the success of restorations (Berglundh et al., 2002; Bernardes et al., 2009). In the present study, on 3 different abutment materials and 3 implant platform connections, the stresses distribution and maximum values, within implant-supported anterior single crowns, were evaluated in the abutment and implant.

For the FEA in this study, the equivalent von Mises criterion was chosen for its capability of summarizing the maximum deformation energy of a given body, even among different materials properties of rigid structures as titanium and zirconia abutments. The stress contours for σ_{vM} occurs both in compressive and tensile areas, on buccal and palatal regions, respectively. The stress plots were color coded according to a single stress level scale for all implants and another for all abutments, providing standard comparison among groups. The maximum and minimum principal stresses values were used in this study to compare the zirconia and hybrid groups among themselves, since those are better criterions for fragile materials, as ceramics. In hybrid models, the Ti base stress was measured in equivalent von Mises because of its ductile characteristic.

The mechanical performance of all-ceramic abutments is a recent concern in the literature. Mechanical tests have been used to analyze the fracture resistance of different abutment material and connections on implant single crown reconstructions. Previous studies reported better mechanical performance of titanium over zirconia abutments for external (Att et al., 2006) and internal connection (Hosseini et al., 2012). Firidinoglu el al. (2012) reported similar fracture resistance and FEA stress distribution among internal connection zirconia and titanium abutment groups. Better fracture resistance results for hybrid over zirconia abutment were reported for both external (Nguyen et al., 2009) and internal connections (Stimmelmayr et al., 2013; Kim et al., 2013; Nguyen et al., 2009). The internal distribution of stresses acquired with FEA provides important data that, gathered with numerical values of maximum stress (σ_{max}, σ_{min}, σ_{vM}) and fracture resistance values of mechanical tests of other studies, may lead to guidelines for restoration improvements.

In the present study, the platform connection had more influence in the stress values and distribution among abutments than among implants. The morse-tapered connection provided the highest values, regardless the abutment material ($\sigma_{\mathbf{max}}$, $\sigma_{\mathbf{min}}$, $\sigma_{\mathbf{v}M}$). The internal hexagon connection provided the highest values for $\sigma_{\mathbf{v}M}$ in implants. The IH implant walls are thinner than MT, what can explain the results for $\sigma_{\mathbf{vM}}$ in implants. The MT abutment/implant interface implies in thinner abutment walls, and associated to the greater zirconia elastic modulus, highest $\sigma_{\mathbf{max}}$, $\sigma_{\mathbf{min}}$, $\sigma_{\mathbf{v}M}$ for MTZr group is justified. The lowest stress values in abutment were found in the EHH, IHTi and IHH, respectively. The larger titanium abutment wall in the IHTi provided the lowest values among Ti groups. The presence of a titanium base significantly decreased the $\sigma_{\mathbf{max}}$, $\sigma_{\mathbf{min}}$ stresses on Zr abutment body from the Zr to the H groups. This fact is due to the better stress distribution provided by the titanium base on the implant neck. Plastic deformation is permitted because of the titanium lower elastic modulus. Unfortunately, zirconia is a very sensitive material and fracture is the first sign of stress overloading - a characteristic inherent to all-ceramic restorations. Due to its high surface hardness and brittleness, high stresses are generated at contact points between the ceramic abutment and any other implant component.

Although the abutment $\sigma_{\mathbf{v}M}$ value for MTH was similar to MTZr, the high $\sigma_{\mathbf{v}M}$ is due to Ti base (293.61 MPa) and not to the Zr abutment body (194.61 MPa), that was even lower than MTTi (286.36 MPa). The $\sigma_{\mathbf{max}}$, $\sigma_{\mathbf{min}}$ values in Zr abutment body (MTH group) were lower than MTZr abutment, implying in better mechanical performance expected in hybrid group. Similar compressive and tensile stresses reduction were observed in EHH and IHH, compared to EHZr and IHZr, respectively.

The present study is pioneer to use FEA for comparison of internal/external and titanium/zirconia/hybrid abutments. Recently, Çaglar et al. (2011) evaluated the stress distribution patterns of internal hexagon connection all-ceramic abutment compared to titanium abutments. The FEA results showed no difference among them. This might be due to the oclusal single point loading used. The 6 steps oclusal loading used in the present study generates more bending moments than a single point loading. Due to the excursive loading, from cingulum to incisal edge, the abutment performance is more challenged, which may have increased the discrepancy among titanium and zirconia groups.

FEA has been used extensively for the prediction of biomechanical performance of dental implant systems. However, its inherent limitations must be considered in interpreting the present study. There were two different interface conditions used in this study. In order to simulate the immediate implant placement and prosthetic loading in the anterior zone, the “contact” type, an non-linear frictional contact element, was used with a 0.3 coefficient assumed between bone and implant (Mellal et al., 2004). This condition allows contact zones to transfer pressure and friction, but not tensions, once that minor displacement without interpenetration are granted between components. The “bonded” type was used on the interfaces of crown, abutment, screw and implant, which were assumed to be perfectly bonded together. This condition interferes in the behavior of stress dissipation through the structures, since it generates tensile stresses in the buccal area of abutment and implant, once these are bonded together. The bonded type was used in this study because there is not a frictional coefficient between titanium/zirconia reported in the literature.

Unfortunately, the number of mechanical trials and clinical long-term studies of implant-supported ceramic restorations is small (Hosseini et al., 2012; Hosseini et al., 2011; Ekfeldt et al., 2011; Bernt Andersson et al., 2001; Vanlioglu et al., 2012; I Sailer, Philipp, et al., 2009; I Sailer, T Sailer, et al., 2009; Kim et al., 2013). New abutment designs should also be proposed and tested preliminarily with FEA for stress dissipation improvement. Therefore, further clinical, virtual and mechanical trials with multiple combinations of abutment connections and material are required for better abutment selection guidelines.

CONCLUSION

Within the limitation of this finite element analysis, the following conclusions can be drawn:

1. The platform connection had more influence than abutment material on stress values and distribution on abutments.
2. The stress values for implants were similar among different platform connections, but greater stress concentrations were observed in internal connections.
3. The hybrid abutments presented similar results to titanium, and better results compared to zirconia abutments.

FIGURES AND TABLES

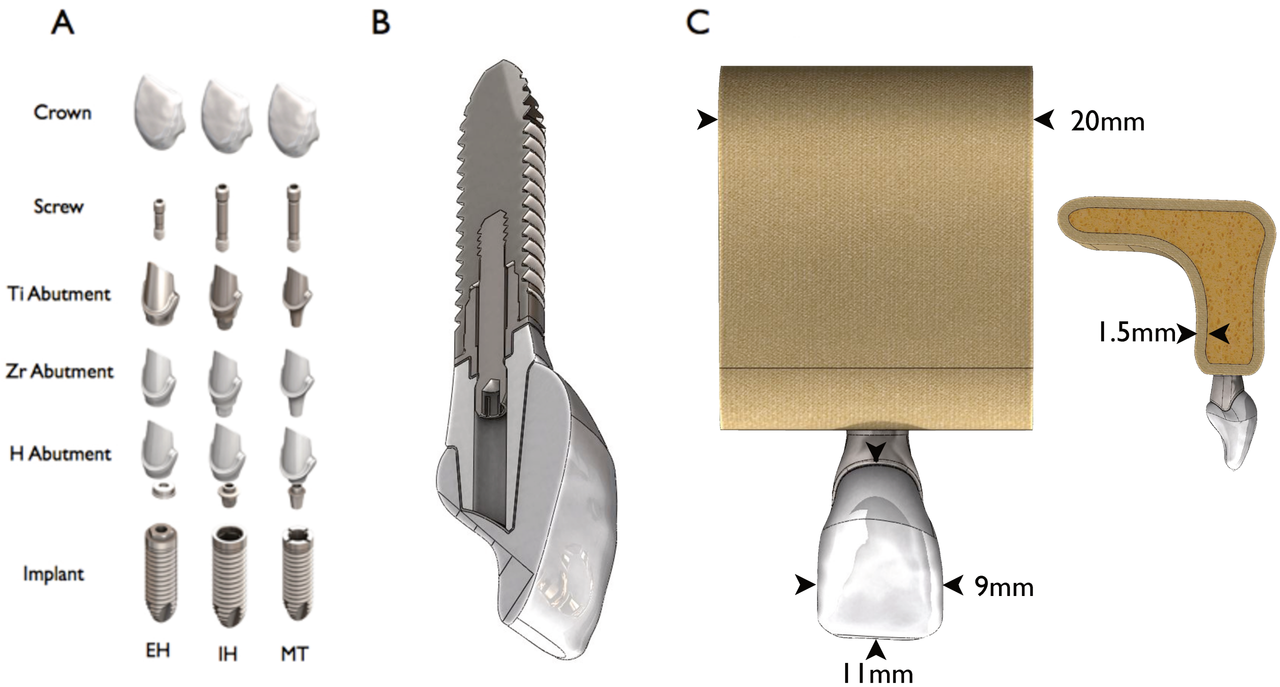

Figure 1. The 3D modeled geometries: A, Assembly parts of all groups; B, Example of IHH restoration slice visualization; C, Complete assembly example of EHTi with dimensions of maxilla segment (20 mm), cortical bone (1.5 mm) and crown (9x11 mm) used for all groups.

Table 1. Experimental design groups

Group	Abutment connection	Abutment material
EHTi		Titanium
EHZr	External Hexagon	Zirconia
EHH		Hybrid
IHTi		Titanium
IHZr	Internal Hexagon	Zirconia
IHH		Hybrid
MTTi		Titanium
MTZr	Morse Tapered	Zirconia
MTH		Hybrid

Table 2. Materials properties adopted in the study.

Material	Young´s modulus (GPa)	Poisson´s ratio	References
Cortical bone	13.6	0.26	Cruz et al. 2009
Cancellous bone	1.36	0.31	Cruz et al. 2009
Titanium (Ti)	110	0.25	Cruz et al. 2009
Zirconia (Zr)	205	0.22	Coelho et al. 2009
Litium Dissilicate (LS_2)	96	0.23	Albakry et al. 2003
Resin cement	18.3	0.30	Li-li et al. 2006

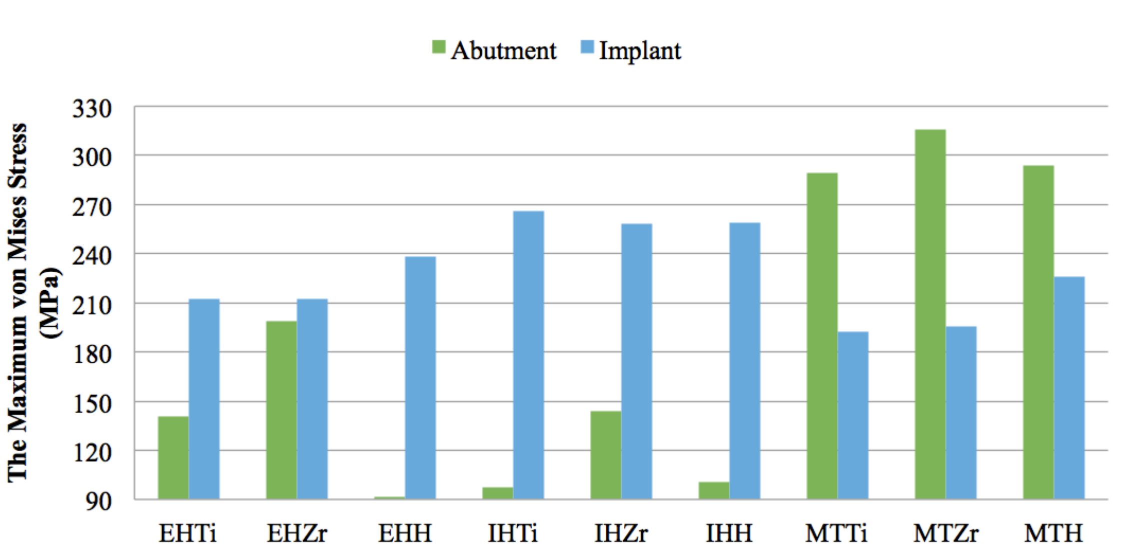

Figure 2. Graph showing the comparison of maximum Equivalent von Mises stresses (MPa) for abutments and implants for all groups.

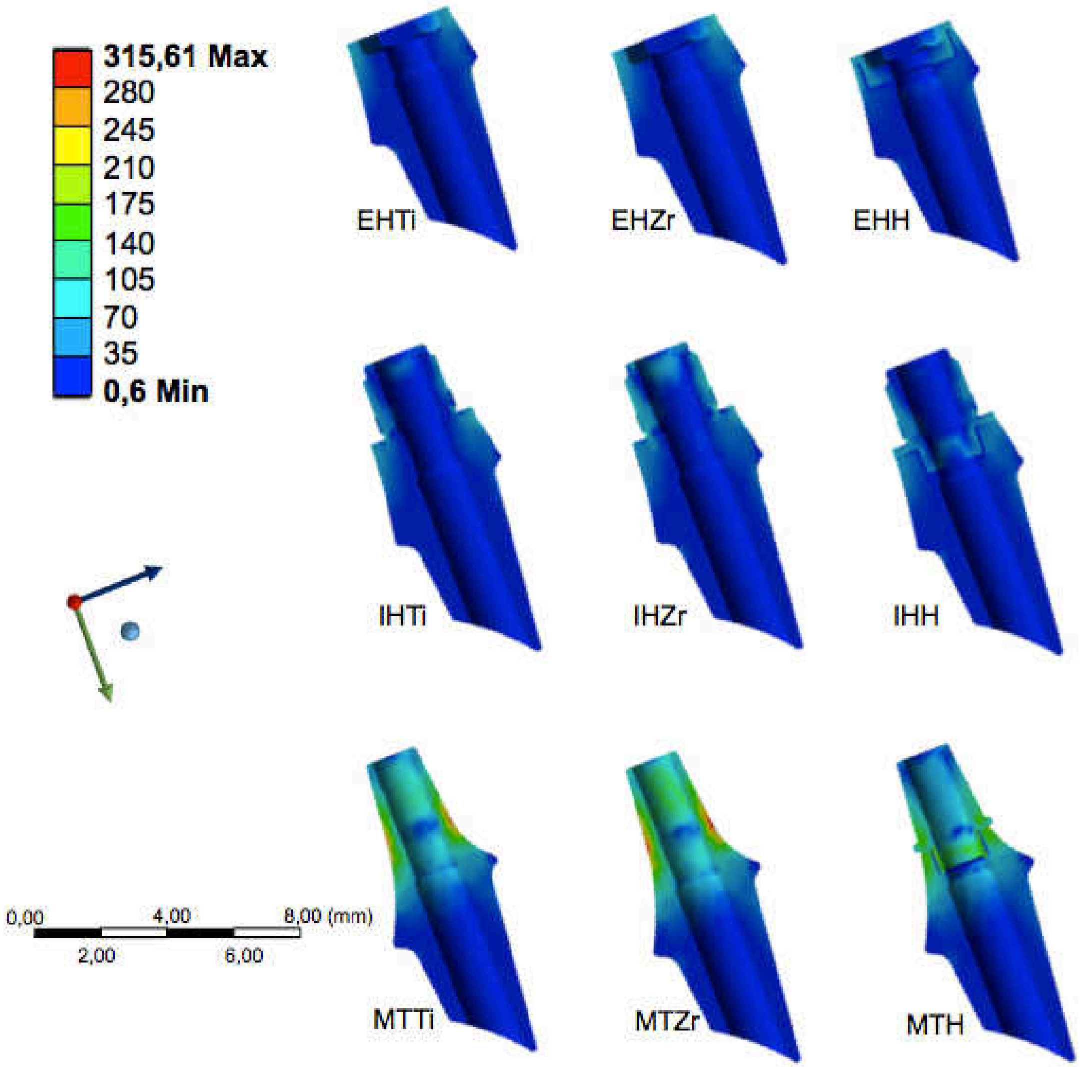

Figure 3. Distribution of equivalent von Mises stresses (MPa) in abutments for all groups.

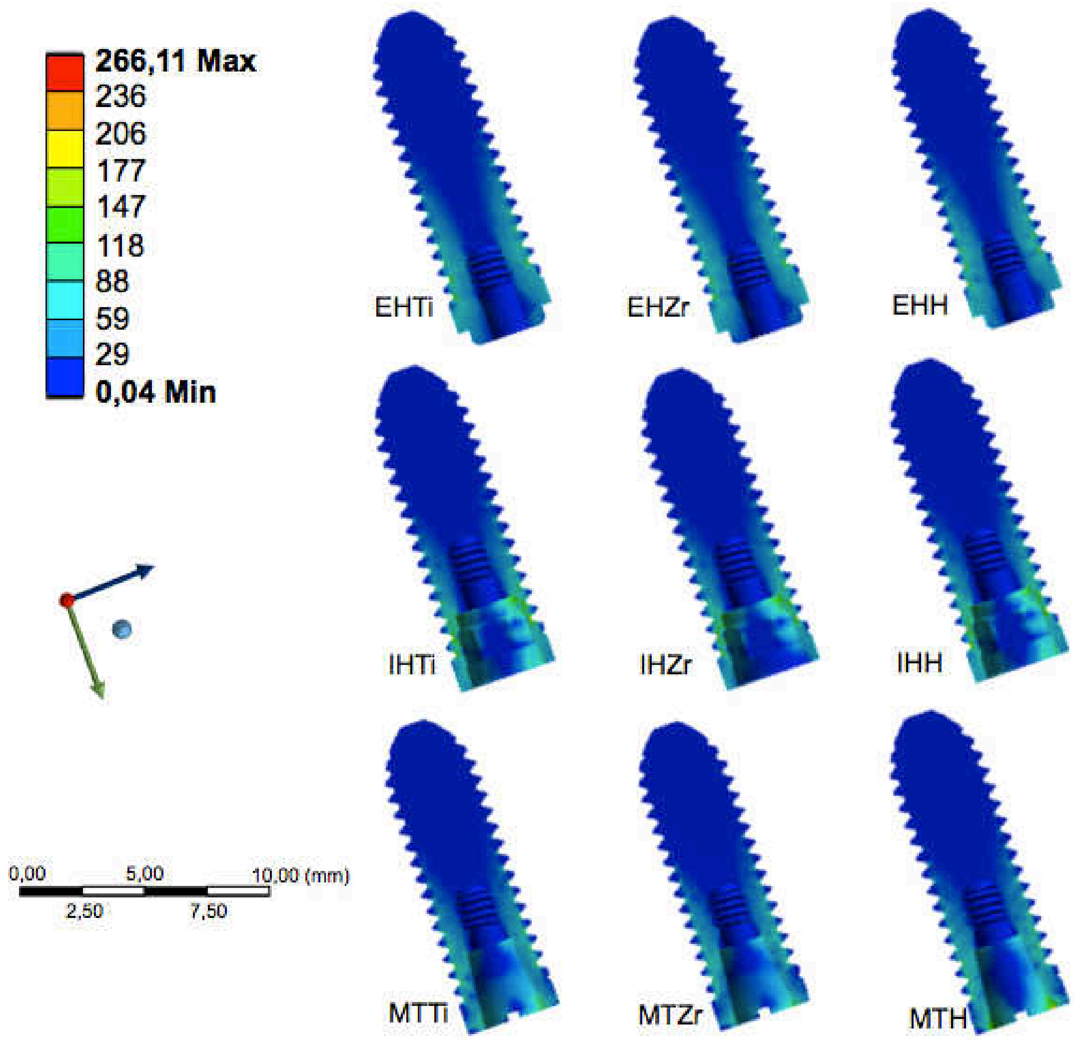

Figure 4. Distribution of equivalent von Mises stresses (MPa) in implants for all groups.

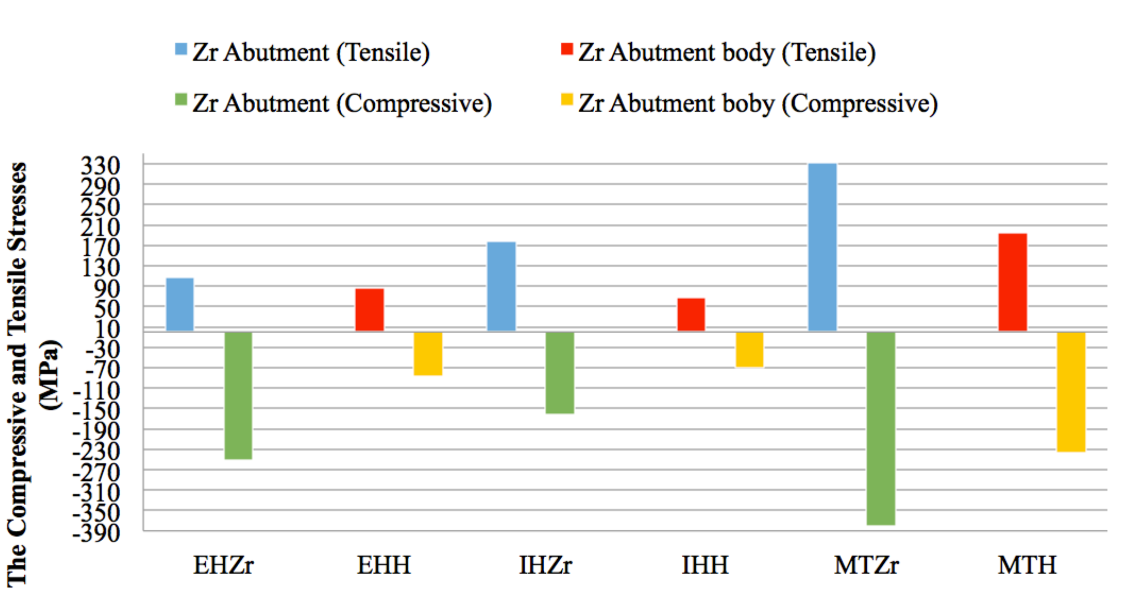

Figure 5. Graph showing the comparison of maximum (tensile) and minimum (compressive) principal stresses among zirconia and hybrid groups.

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CONCLUSÃO

Tendo em vista as limitações do método dos elementos finitos utilizado no presente trabalho, concluiu-se que o tipo de conexão teve maior influência que o material constituinte nas tensões acumuladas nos pilares, sendo que os pilares híbridos tiveram comportamento mecânico semelhante aos de titânio, que por sua vez foi melhor que os pilares em zircônia. A distribuição da tensão nos implantes foi similar, sendo as mesmas maiores nos implantes de conexão interna.

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APÊNDICE 1 – Ilustrações de Materiais e Métodos

1. Construção do modelo tridimensional da maxila:

.

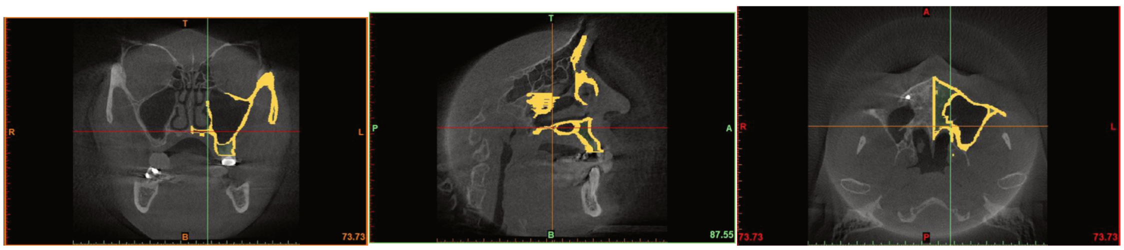

Figura 1: Imagens de tomografia computadorizada de um paciente desdentado total superior. Os cortes tomográficos foram importados para o *software* Mimics, onde foram classificados de acordo com a densidade do osso em graus de cinza.

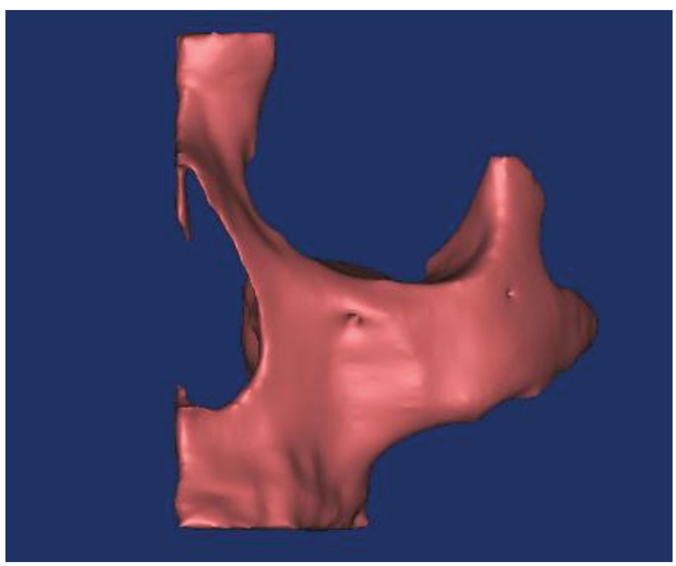

Figura 2: Primeira reconstrução da maxila até o osso zigomático utilizando o *software* Mimics.

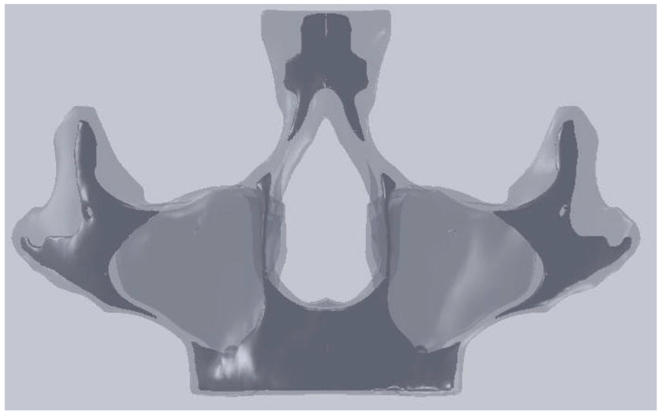

Figura 3: O modelo inicial foi exportado para o *software* SolidWorks (SOLIDWORKS 2009, SOLIDWORKS CORPORATION, MA, EUA) a fim de que o modelo final apresentasse osso cortical e medular.

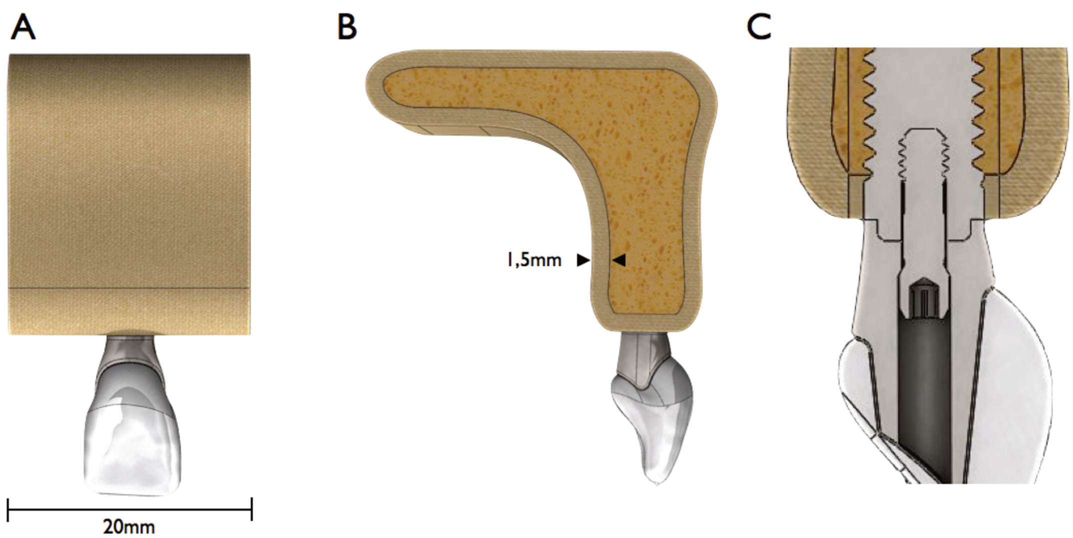

Figura 4: A. A partir do modelo inicial, obteve-se as medidas de referência para a extrusão de uma seção maxilar em 20 mm. **B.** Vista lateral demonstrando a espessura de 1,5 mm da cortical óssea. **C.** A crista óssea foi regularizada para o total assentamento da plataforma dos implantes, posicionados a nível ósseo.

2. Construção dos modelos tridimensionais da coroa:

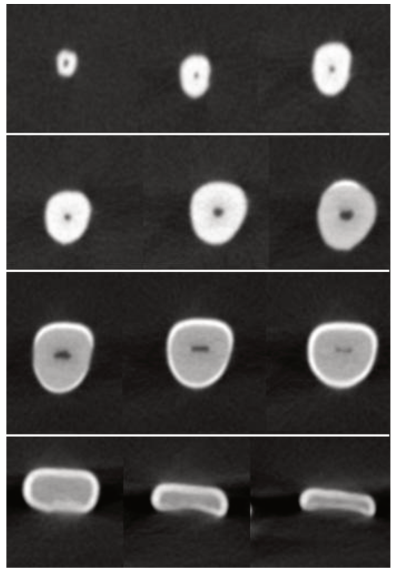

Figura 5: Seqüência de imagens da microtomografia computadorizada (Tomógrafo Computadorizado de Feixe Cônico – KODAK 9000 3D) de um incisivo central hígido.

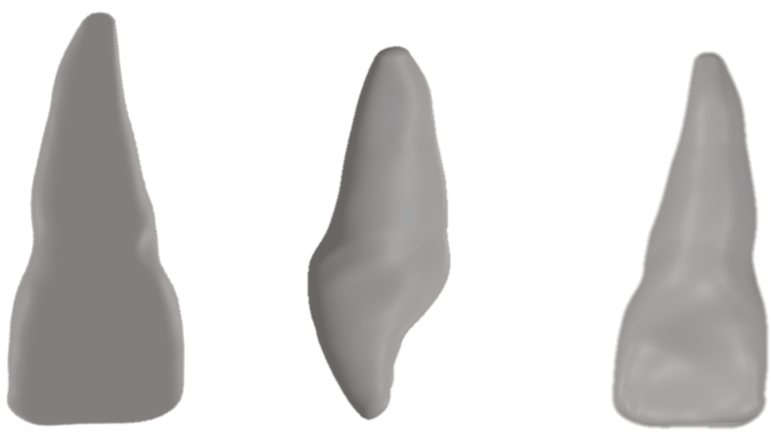

Figura 06: As imagens DICOM foram importadas para o *software* InVesalius (CTI – Renato Archer) para a reconstrução tridimensional.

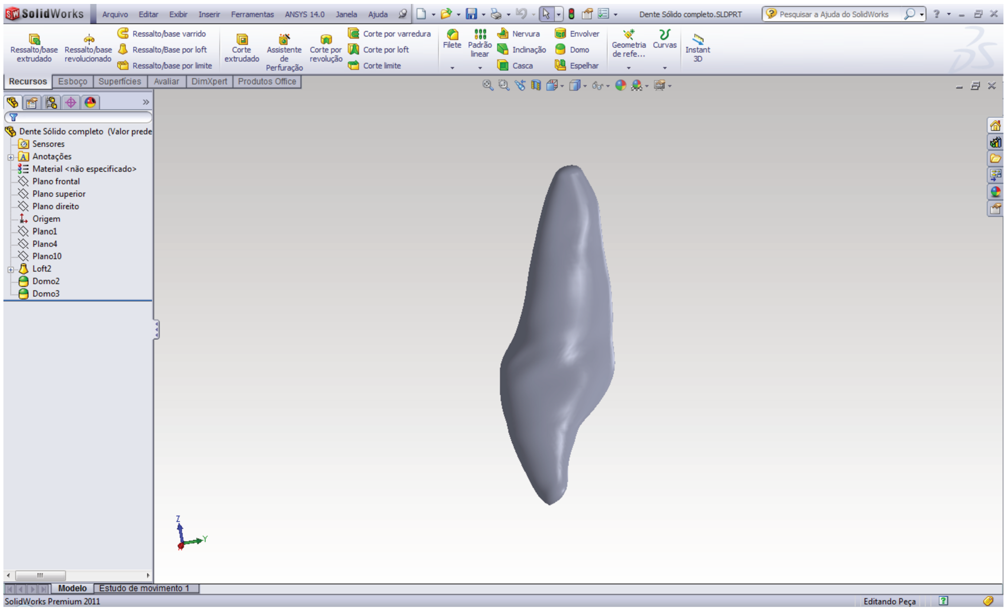

Figura 07: Interface do *software* SolidWorks utilizado para alteração dos modelos tridimensionais.

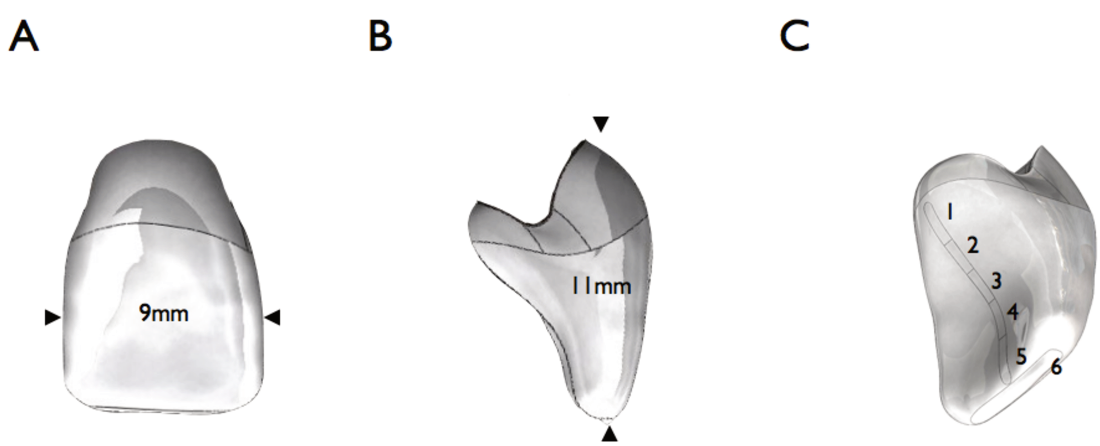

Figura 08: A. Vista vestibular da coroa final em dissilicato de lítio com 9 mm de distância mesio-distal. **B.** Vista proximal com distância cérvico-incisal de 11 mm. **C.** Vista palatal demonstrando as 6 faces de carregamento oclusal.

3. Construção dos modelos tridimensionais dos implantes, parafusos e pilares.

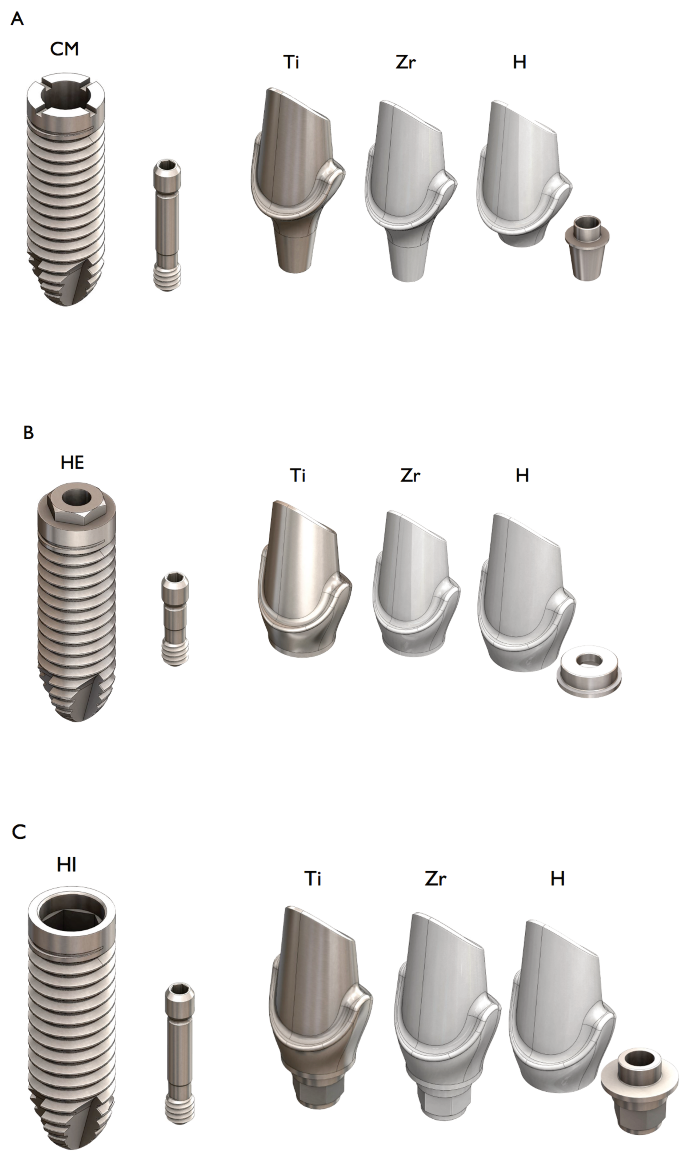

Figura 9: A partir de modelos disponibilizados pela empresa Neodent (Titamax EX 4x13 mm; Parafuso Passante; Munhão Universal CM em titânio; Neodent, Curitiba, Brasil) (A) foram confeccionados implantes de conexão hexagonal externa (B) e interna (C) e respectivos pilares em titânio, zircônia e híbrido.

4. Montagem dos Modelos em Grupos Experimentais:

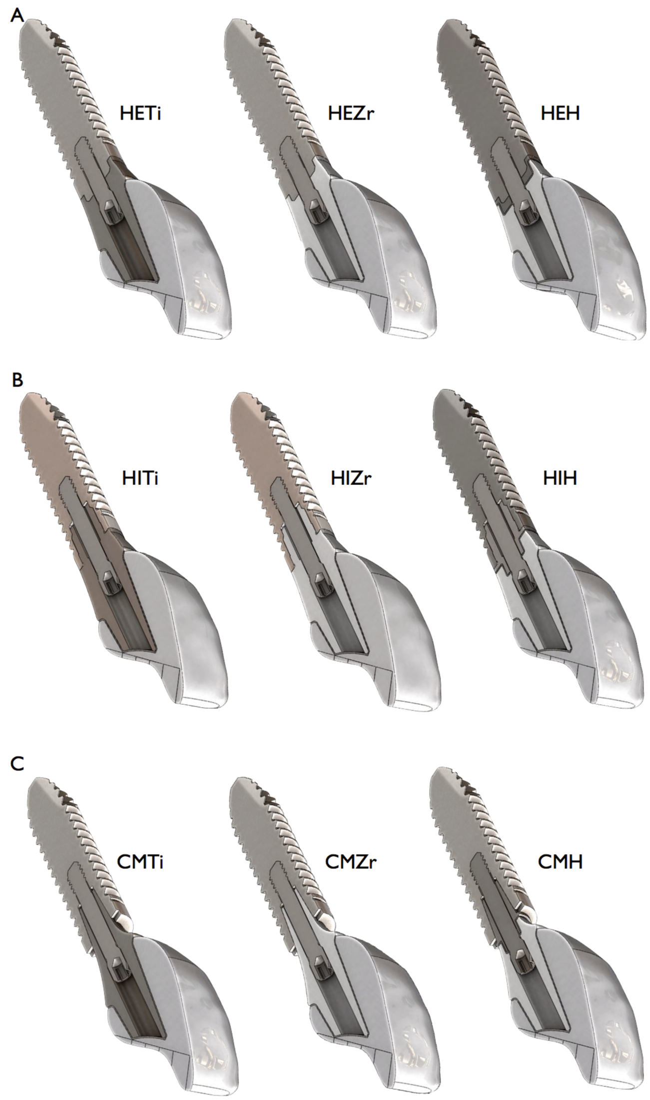

Figura 10: A. Montagens dos grupos de conexão hexagonal externa com pilares em titânio, zircônia e híbrido ; **B.** Conexão hexagonal interna com pilares em titânio, zircônia e híbrido; **C.** Conexão cone morse com pilares em titânio, zircônia e híbrido.

5. Análise pelo Método dos Elementos Finitos:

5.1. Confecção da malha.

Tabela 1: Número de elementos e nós de cada modelo

GRUPO	ELEMENTOS	NÓS
HETI	91.455	159.995
HEZR	91.451	159.986
HEH	93.454	164.162
HITI	92.579	162.425
HIZR	92.579	162.425
HIH	93.819	164.975
CMTI	91.085	159.965
CMZR	91.312	160.250
CMH	93.582	164.689

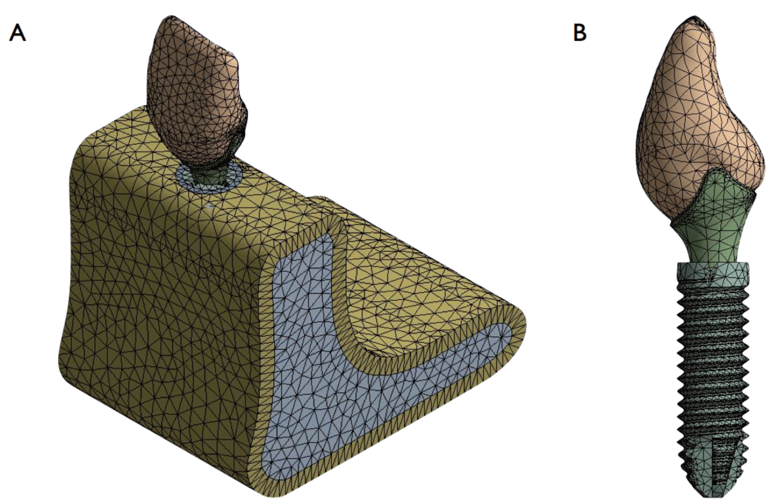

Figura 11: Confecção da malha através da convergência de análise à 6% determinada por elementos tetraédricos de 0,7 mm. **A.** Montagem CMTi **B.** Restauração CMTi**.**

5.1: Carregamento

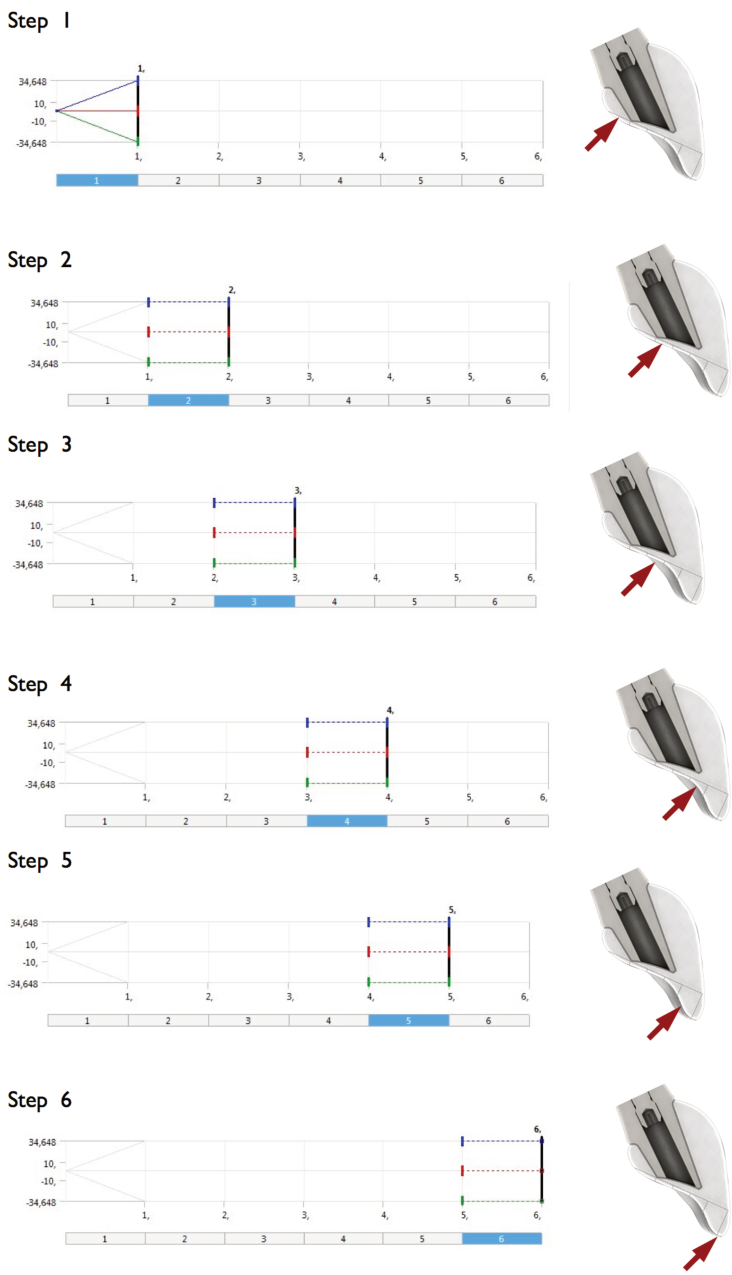

Figura 12: Carregamento oclusal realizado em 6 etapas: 49N aplicado obliquamente (45º) da região de cíngulo à borda incisal.

ANEXO 1 - Comprovante de submissão do artigo ao periódico Journal of Prosthetic Dentistry

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